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TECHNOLOGY UTILIZATION REPORT

Technology Utilization Division

THE RETROMETER: A Light-Beam Communications System

From Langley Research Center
Langley Station, Virginia

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Source: Numa E. Thomas
Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington D.C. *March 1964*

Foreword

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National Aeronautics and Space Administration

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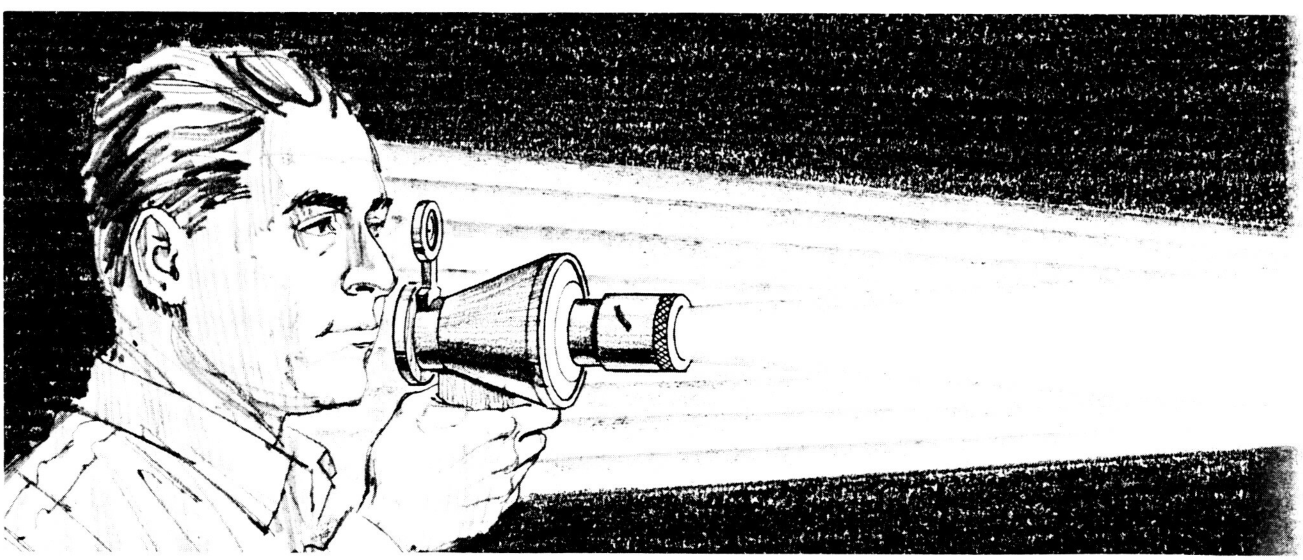
Contents



The Retrometer: A Light-Beam Communications System

Summary

A new system of voice communications transmitted on a beam of light is described. It differs from prior systems in that the originating station requires no power other than that of the human voice. The advantages and limitations of the Retrometer are briefly discussed, and some potential applications are analyzed. A detailed description of an experimental model is given, so that interested persons can construct a working model for experimentation and development.

1. Introduction

During an investigation of optical methods that might be applied to communications between ground and a reentry vehicle during the radio-blackout period, and between rendezvousing space vehicles, a novel communications system was devised by Numa E. Thomas, of the Langley Research Center. This system appears to have applications other than in space, and indeed could be used for applications other than voice communication. The purpose of this paper is to describe this system, summarize the characteristics observed in preliminary development, and outline sufficient detail of its construction as to permit others to build experimental models for further development. It is hoped that this summary of a relatively undeveloped concept will challenge others to further investigation and measurement.

Figure 1. Source/receiver unit at left above transmits a beam of light and also collects and demodulates reflected beam. Corner-reflector unit at right has one flexible reflecting surface that is acoustically deflected.

The Retrometer---given this name because the light beam over which voice signals are sent is returned directly to its source by a corner reflector ---consists of three major functional parts: a light source, a corner reflector, and a light-collection system. The light source and the light-collection system are housed in one unit, the source/receiver unit. The corner reflector, which acts as the microphone in this communications system, is a passive modulator unit, requiring no power other than the human voice.

2. Technical Description

The source/receiver unit consists of a source of light with provision for focusing it into a narrow beam; optics for collecting reflected light and directing it on a photosensitive cell; and an audio amplifier and speaker. The corner reflector has three mutually perpendicular reflecting surfaces, and these have the unique ability of returning a light beam exactly to its source. In other words, the three reflecting sides of a corner are able to return an incident light beam to its source even though the corner is not as accurately oriented as a single mirror would have to be.

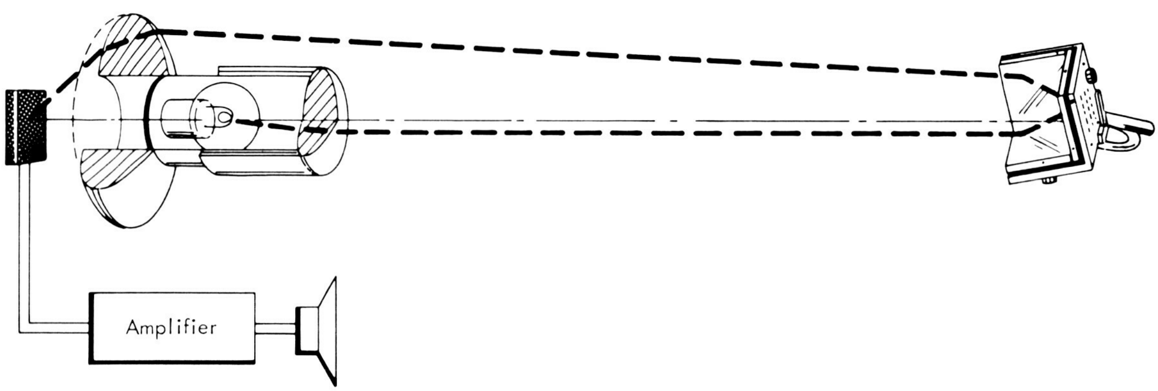
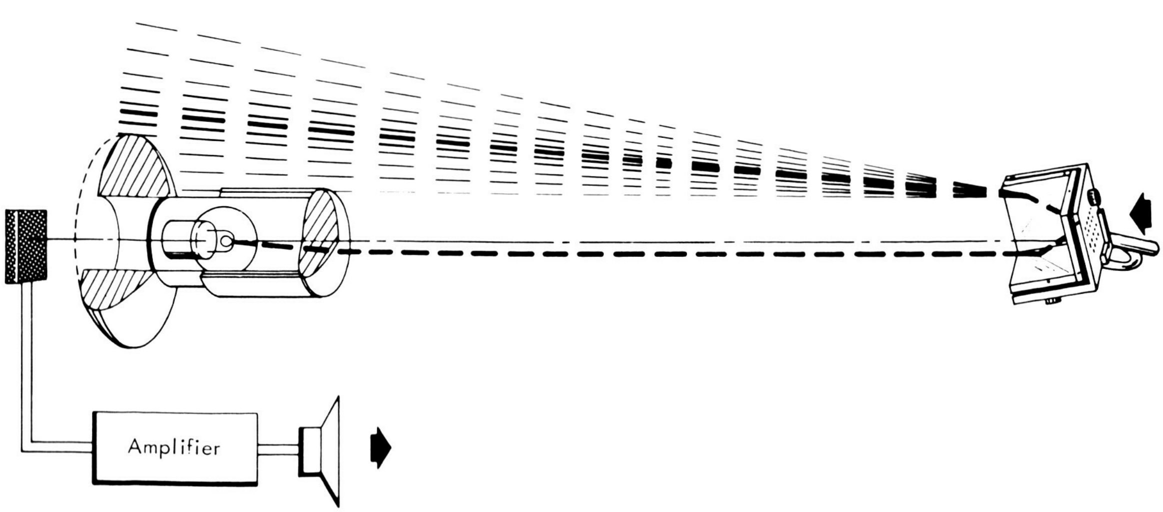


Figure 2. With no signal impressed on corner reflector, the return beam is uniform, above. But when the diaphragm vibrates acoustically, the return beam is modulated accordingly, below.



Two of the surfaces in this corner reflector are rigid front-surface mirrors and the third is a flexible, highly reflective diaphragm. The flexible surface, vibrating acoustically in response to the human voice, slightly displaces the returning light beam and thus modulates it. Information is thus carried on the reflected beam in such a manner that the energy per unit area falling on the collecting optics and the photocell varies in proportion to the modulation impressed on the flexible surface of the corner reflector. The photocell converts the fluctuations of the reflected beam into an electrical output that is amplified and converted into sound by the amplifier and speaker.

Although major performance characteristics of the Retrometer have not been fully explored at this writing, the basic capability has proved impressive in Langley tests. An initial laboratory model provided excellent communication in full daylight at distances up to a mile on a 25-watt light source. A more compact model was constructed for the express purpose of demonstrating the principle. This model, which is the one shown in the accompanying illustrations, uses only a six-watt bulb. It provides satisfactory voice communication at distances up to 200 feet.

Other characteristics noted include substantial insensitivity to precise aiming of the passive modulator unit, to thermal gradients in the atmosphere, and to a high level of ambient light. The first is of course explained by the optical characteristics of a corner reflector. In practice, it was found that the corner reflector may be off axis by as much as 20 degrees without noticeable loss of volume. Refraction gradients undoubtedly do bend the beam in passing from the source to the reflector; but since the returning light encounters the same gradients in the opposite direction, the effects are self-compensating. As to operation in ambient light, the level of light may be high in daytime but it is relatively unchanging compared to voice frequencies; the receiver system thus is able to separate the modulated component from the bright but comparatively unchanging ambient light.

The system is of course line-of-sight in character, although, in fixed-site installations, an intervening mirror might be used to effect an angular path. The presence of smoke, fog, or dust does not cause failure until sufficiently dense to decrease the round-trip energy below the receiver threshold. Windows or glass partitions do not noticeably interfere with communications. When the diaphragm surface of the reflector is distorted by input signals, the return beam is partly deflected from a parallel path and dispersed. The net effect of this deflection and dispersion is to vary the energy received by the collecting optics in proportion to the distortion of the flexible diaphragm. The precise character of the modulated wave front was not determined. The effective percentage of modulation is, apart from the amount of input, a function of the distance between source/receiver and reflector: when the distance is short the percentage of modulation is low. As distance increases, the percentage of modulation also increases, which in effect increases sensitivity. This is useful because it tends to compensate for the reduction in returned energy caused by distance.

3. Potential Variations in Retrometer Design

Relatively undeveloped as presented in this report, the Retrometer can obviously be refined through many different approaches. Such development might naturally arise from adaptation of the concept to a variety of specific applications. For example, various types of collecting optics, including Fresnel lenses, might be used for experimentation and development. See Fig. 3 for two variant designs of collecting optics that might have special merit.

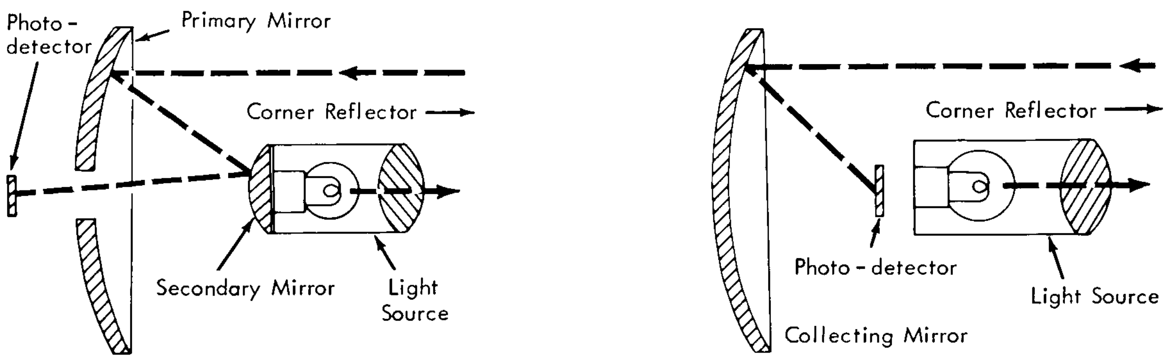


Figure 3. Alternate forms of collecting optics are developmental possibilities for use in special applications.

In the same manner different sources of energy, including those in the microwave, infrared, and ultraviolet portions of the spectrum, could be investigated. For sophisticated long-range systems the use of a laser as a light source might well be examined. Again, various types of photodetectors could be explored, including the use of photomultipliers. A number of relatively simple development ideas also suggest themselves: a protective but transparent cover for the corner reflector, various materials for the flexible surface, electrostatic or mechanical rather than acoustic drive for the flexible surface, and various arrangements of elements to prevent acoustic feedback, including feedback from the speaker to the light filament.

Another obvious area for investigation would be the use of modified equipment to permit two-way communication, most probably by mounting a corner reflector with each of two or more source/receivers. Here development effort could determine the degree of need for a push-to-talk circuit that would extinguish the light source of the listener, preventing it from desensitizing the other unit. An additional area for inquiry would be to investigate other than coaxial mounting of the elements on the source/receiver unit. Side-by-side mounting of the two optical systems might be tested, as well as arrangements of receiving lenses disposed around the projecting lens.

4. Advantages and Disadvantages of the Retrometer

Experience with models constructed so far suggests that the Retrometer has certain basic advantages and limitations, some of them susceptible to modification by further development work.

Among the merits are these:

- Low cost, particularly for the corner reflector or speaking station;
- No power required at the speaking station;
- Private communications, since the return signal is confined to a narrow beam and could be intercepted only with great difficulty.
- No need for precise pointing of the corner reflector, a marked advantage over prior light-beam communications systems; and
- Easy selection of a number of stations from a central point without switching mechanisms.

The chief limitations are those inherent in one-way communication: difficulty in alerting an inattentive station, inability of the source/receiver station to question remote stations specifically, and at a remote station the psychological drawback upon the speaker of being uncertain that his transmission is received.

In some applications, notably those at long range where the exact location of the remote corner reflector is not known, the problem of acquisition (i.e., of finding the reflector and establishing communication) may present a problem. To aid in acquisition the beam may be somewhat defocused to increase the probability of hitting the reflector, though at extreme ranges defocusing exacts its penalty by decreasing available energy. Again, during scanning for acquisition, the operator of the corner reflector may need to be continuously sending a signal, since the beam could otherwise sweep by without detecting his presence. Acquisition is of course no problem in the case of fixed-site installations.

5. Some Potential Applications for the Retrometer

Successful development of systems based on this principle might find use in many areas.

Among military applications are air-sea rescue operations; air-to-sea, ship-to-ship, and ship-to-shore communications; air refueling operations; tactical communications; and clandestine operations. Certain aspects of the Retrometer make it inviting in several of these applications, notably the fact that its communications are secure, that it causes no stray electromagnetic radiation, and that the corner reflector could readily be parachuted or packed in life rafts and survival kits.

Among commercial applications are surveying; use on construction sites (particularly those where radio transmissions are interdicted by blasting operations, or rendered difficult by steelwork or tunnels); use in steel mills, where high noise levels and radio-frequency interference are problems; light-plane-to-tower communications; communications during special events and political conventions; and emergency situations, including forest fires, shipwreck, and other disasters.

Among space applications are rendezvous and docking, emergency communications, and optical telemetry.

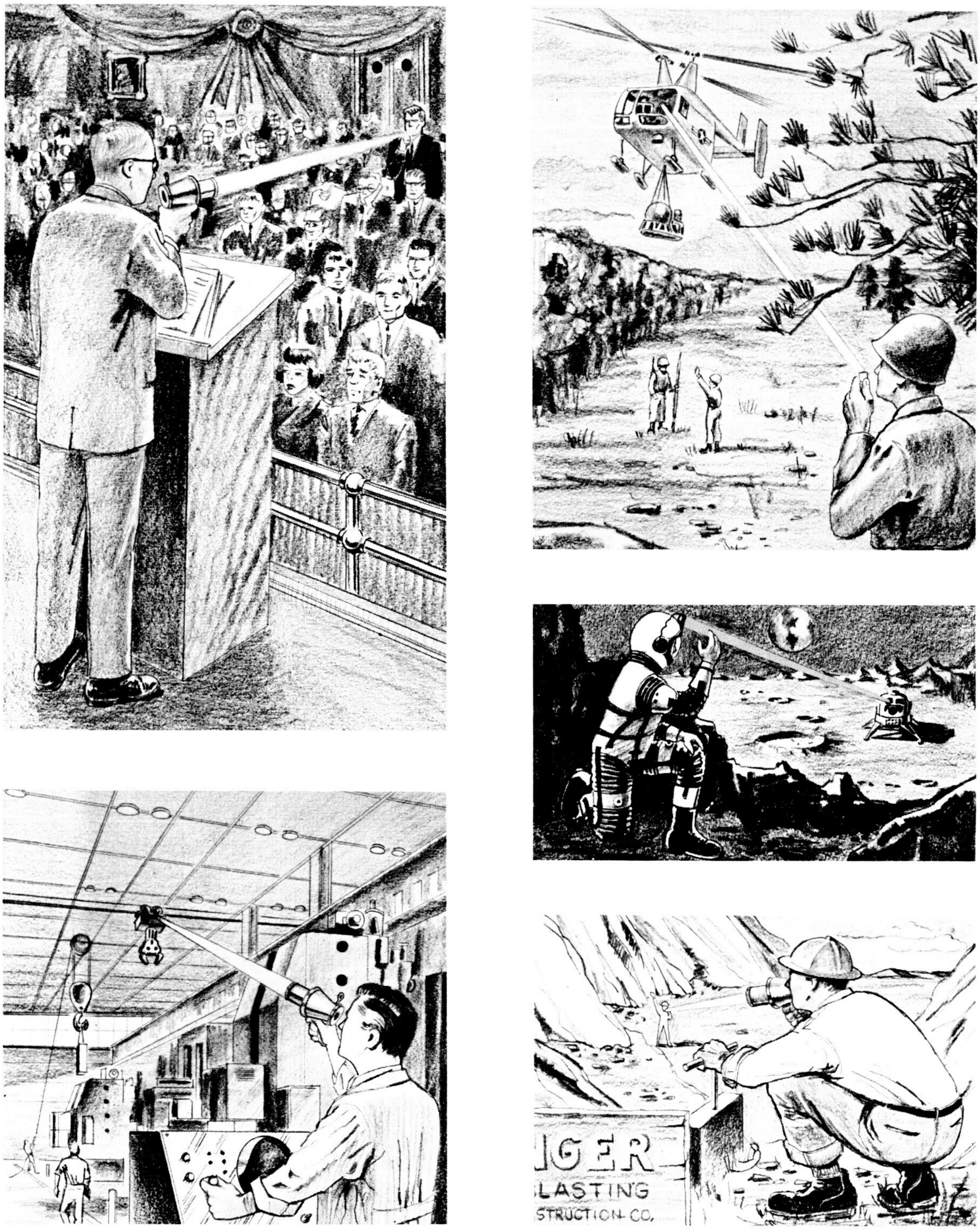


Figure 4. A variety of applications can be envisioned. Among them are audience participation, ground-to-air communications, space communications, communications at construction sites, and telemetry of moving machinery.

It should be pointed out that the Retrometer is by no means limited to voice communications. A number of applications may be conceived where the Retrometer might serve as means of telemetry. For example, a remote wind-velocity sensor may be envisioned. If a ribbon fastened at one end is exposed to the wind, the free end vibrates at a frequency that is a function of wind velocity. The corner reflector might be coupled to the fixed end of a ribbon so that the frequency of the return signals could be converted into a reading of wind velocity. Other related applications might include analysis of vibrations of moving equipment, or telemetry of heart and respiration rates of animals or humans without the restrictions on free movement caused by trailing wires.

Another area where the Retrometer might find highly imaginative use is in highway traffic control. It is conceivable, for instance, that highway authorities might give instructions or advice to motorists by modulating messages on corner reflectors installed at special points along highways, providing information on special road conditions ahead or issuing speed warnings. Possibly a car's headlights might serve as the light source. As to the difficulty that only equipped cars would receive such messages, this would ultimately be solved only by factory installation, although garage installation on existing cars might be feasible. An interim measure, however, can be envisioned in the form of "loaner" receivers that might be quickly fitted to cars at entrances of long toll roads, and returned at exits.

Two of the possible applications of the Retrometer have attracted special interest in analyses of possible uses that have been made so far. These are lightplane-to-tower communications, and use for audience participation—questions from the floor---in large meetings. In the former case the concept would be an easy extension of the system, already in use for traffic control of planes without radios, of red and green light guns that send landing-instruction signals. Further, since many lightplanes have radio receivers only, a combination of an inexpensive Retrometer reflector in the plane and radio receiver would in effect permit two-way communication with the tower. In all aircraft, moreover, including those with full electronic gear, a Retrometer reflector could provide emergency back-up in case of radio failure.

In the audience-participation use, it is envisioned that lightweight and low-cost reflectors would be distributed through the auditorium, perhaps chained to seat backs. By directing the source/receiver at anyone standing up on the floor, a person at the rostrum could select and receive questions or comments. It's worth noting that here also there is the effect of two-way communications, the public-address system in the auditorium serving as the other link.

6. Prior Related Systems

The simple use of mirror-reflected sunlight for communications is of course very old. Greek soldiers used mirror signals in the pre-Christian era; the British Army used the mechanically ingenious heliograph for code signals during the conquest of India. The basic principle of audio transmission by modulated light beams appears to have been originally conceived by

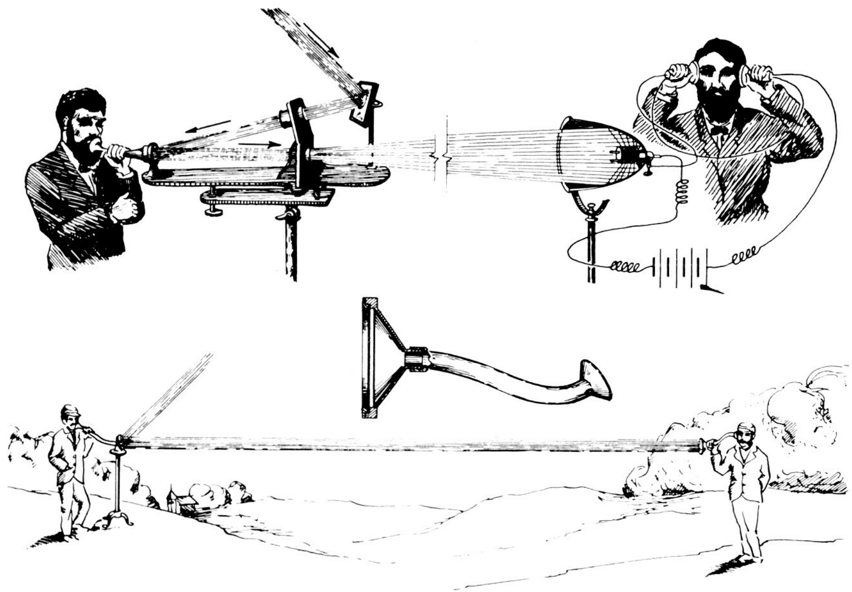


Figure 5. The Bell Photophone of 1880 appears to have been the first patent for voice communication by light.

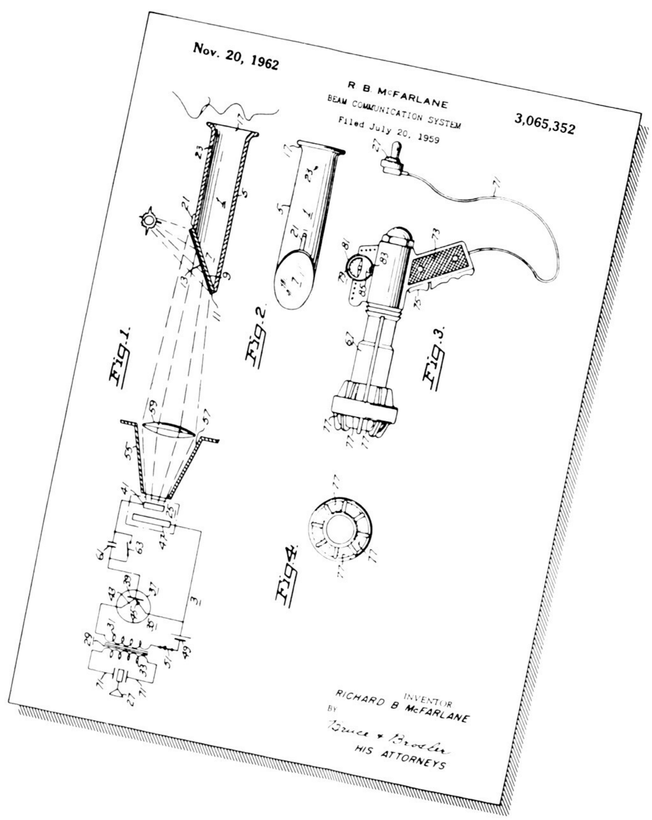


Figure 6. In this relatively recent patent, the Sun is the light source. The corner-reflector concept is not used.

Alexander Graham Bell. A patent for a "Photophone" was issued to him in 1880, although the rudimentary nature of his apparatus (Fig. 5) leaves reasonable doubt as to its effectiveness.

Since that time a number of patents have been issued that represent apparent refinement or improvement on the concept. With one exception, however, all such patents require a power supply at each station in the system. The exception is a "Beam Communication System" patent issued to R. B. McFarlane in 1962, where a remote speaking station is voice-powered. It does require the sun as a light source, however, and therefore retains a substantial limitation on freedom of use.

The Retrometer is believed to be alone among light-beam communications systems in offering a simple, convenient, and inexpensive device at one terminal.

7. Description of an Experimental Retrometer

The experimental Retrometer shown in Figs. 7 to 11 can be constructed in any small electronics and optical shop. Many of the details are noncritical and can be varied according to desire and facilities. The model here described, which is the second model developed at the Langley Research Center, has been found to be convenient, portable, and effective up to ranges of several hundred feet.

The complete Retrometer system, shown in Fig. 7, consists of a battery case, the source/receiver unit, and the corner-reflector unit. In the battery case, which may for convenience be a camera-equipment bag with shoulder strap, are five 1.35-volt mercury cells to power the light source, and a 9-volt battery to power the transistorized amplifier. A four-wire cable and plug connect the battery case to the source/receiver unit.

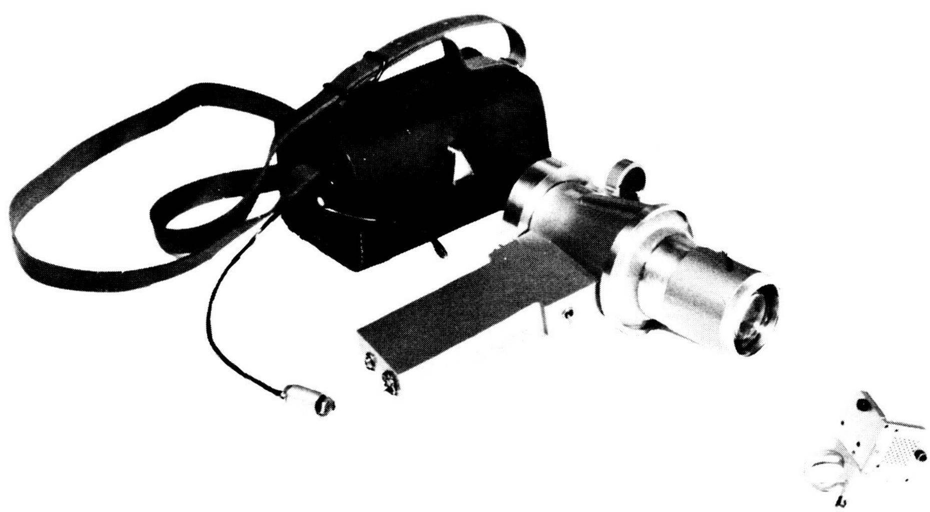


Figure 7. Built by Langley Research Center for the purpose of demonstrating the principle, this Retrometer is light, compact, and simple to use. It gives communication to 200 feet on the energy of one six-watt bulb.

The source/receiver, shown in exploded view in Fig. 8, consists of three functional subassemblies: the light source, the light-collecting unit, and the amplifier and speaker. Some notes on each, plus the illustrations, should supply sufficient details for construction.

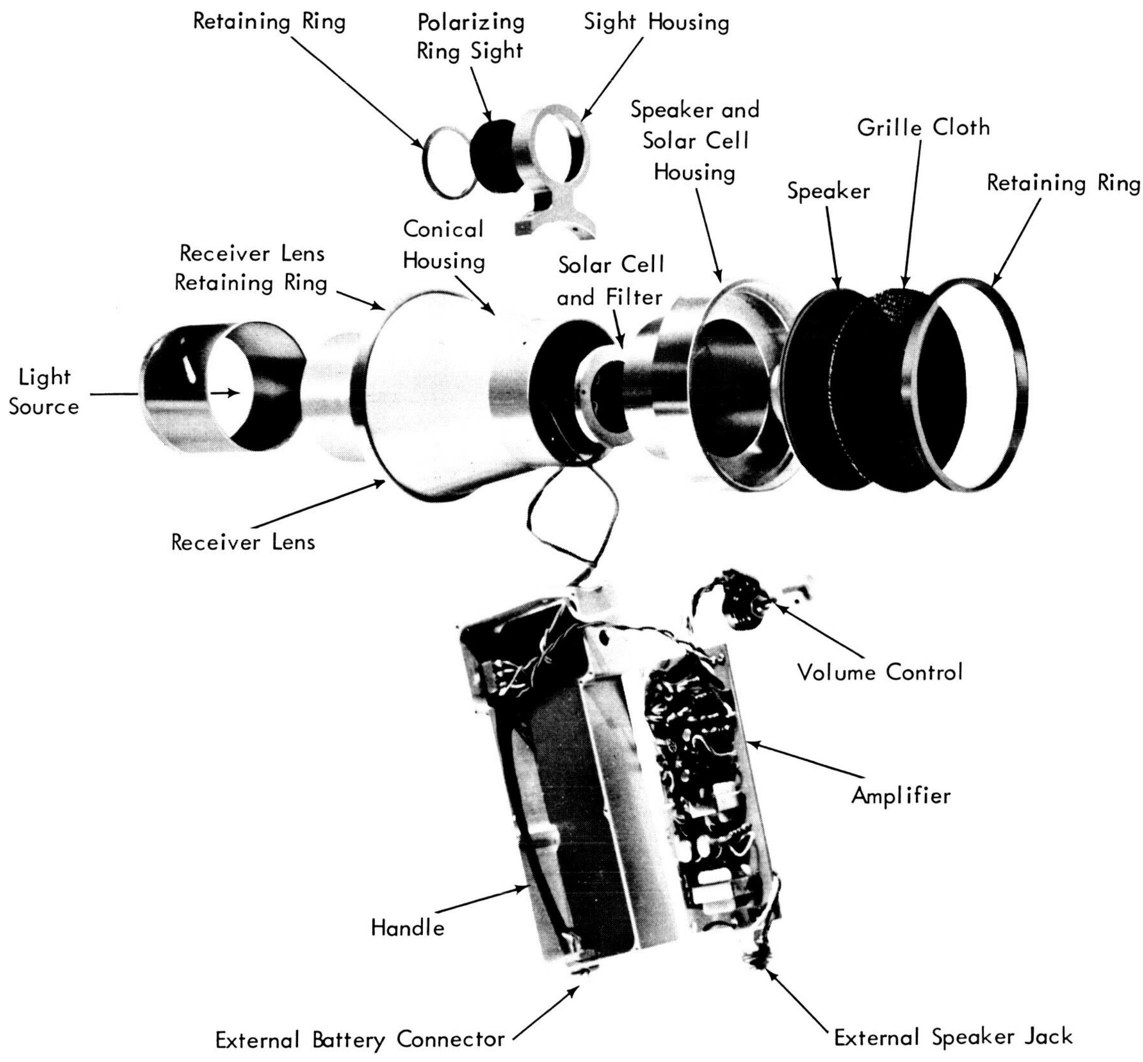


Figure 8. Exploded view of the Langley demonstration Retrometer. Many details of the design are noncritical.

The light source is a 6-watt 6-volt bulb located at the focus of a simple f/1 lens 2 inches in diameter. (A highly corrected lens is not essential; a good condenser lens will suffice.) The precise mounting of the bulb in relationship to the lens is also uncritical if means is provided to vary the distance between them to widen or narrow the beam. Fig. 9 is an exploded view of the light source. The optional infrared filter permits operation in the infrared mode if the photoelectric cell selected responds to this radiation.

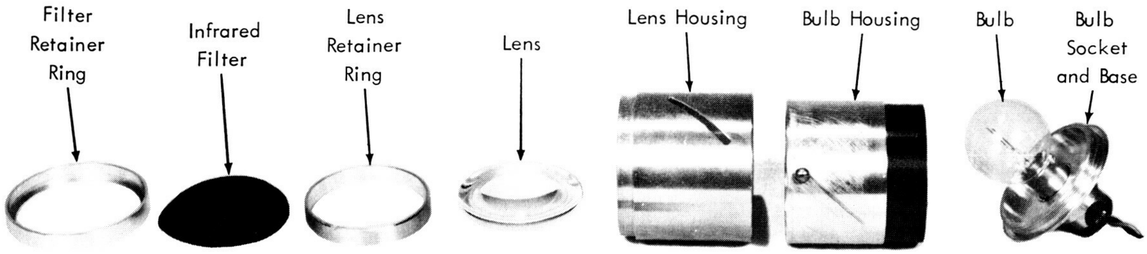


Figure 9. Exploded view of the light-source subassembly. Optional infrared filter helps reduce fluorescent hum.

The light-collecting unit is a simple f/1 lens 3 inches in diameter. If facilities are available for conveniently cutting a 2-inch hole from its center, this permits compact coaxial mounting of the units; if such facilities are not at hand, more extended coaxial mounting may be used. In the model shown, Langley used a silicon solar cell for the photoelectric receiver, with an effective working area 1 centimeter square. It is of course located at the focus of

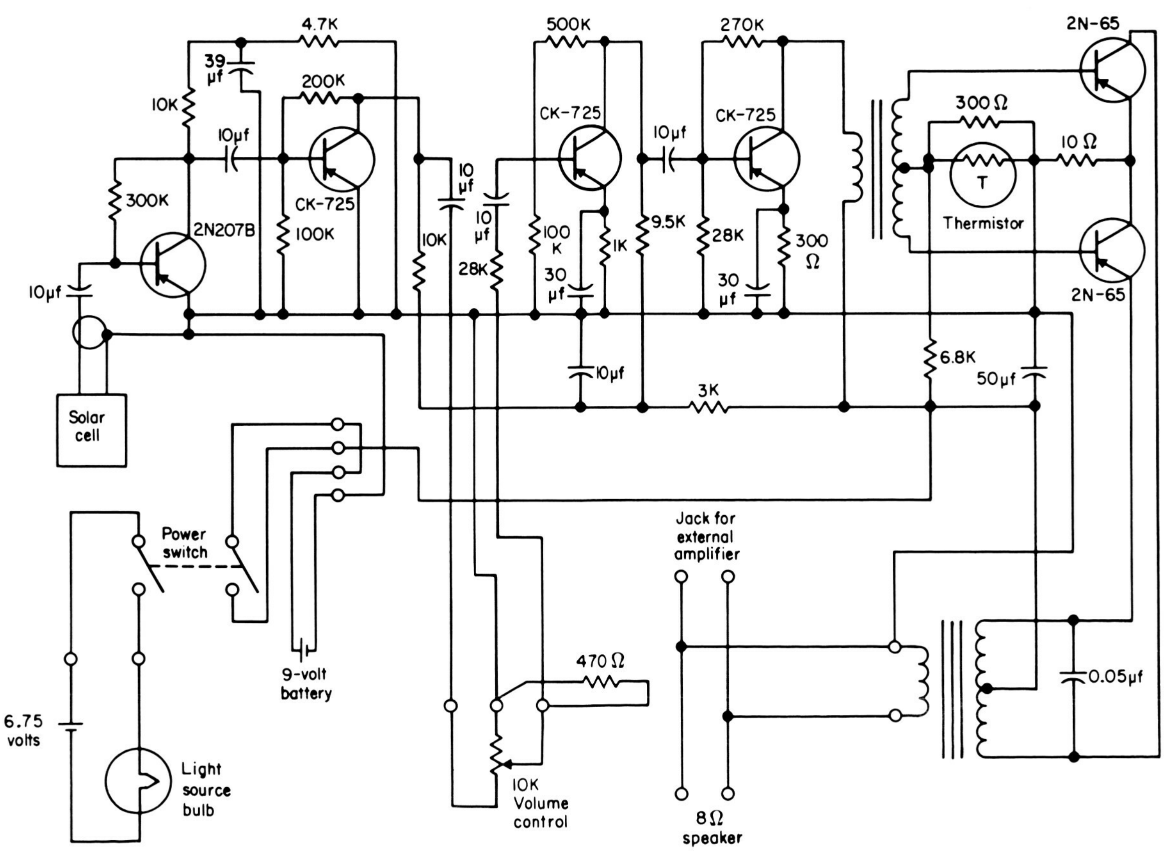


Figure 10. Schematic diagram of the source-receiver unit. Other amplifier circuits having sufficient gain (100 db.) would also serve. Photocell is a silicon solar cell 1 by 1 cm. in area with an output of 100 milliwatts.

the collecting lens. Because the solar cell used here is responsive to the infrared, a second infrared filter was used in front of it to reduce the 120-cycle hum resulting from use indoors under fluorescent lights. (Equivalent silicon photoelectric cells, with 1 by 2 cm. area and delivering up to 100 milliwatts under full sunlight, may be purchased from mail-order electronic supply houses.)

The amplifier is a six-transistor audio amplifier having sufficient gain (100 decibels) to drive the speaker from the small voltages supplied by the photoelectric cell. The permanent-magnet speaker is 2 3/4 inches in diameter, with 8 ohms impedance on the voice coil. An on-off switch, volume control, and output jack for possible use of external speakers are provided.

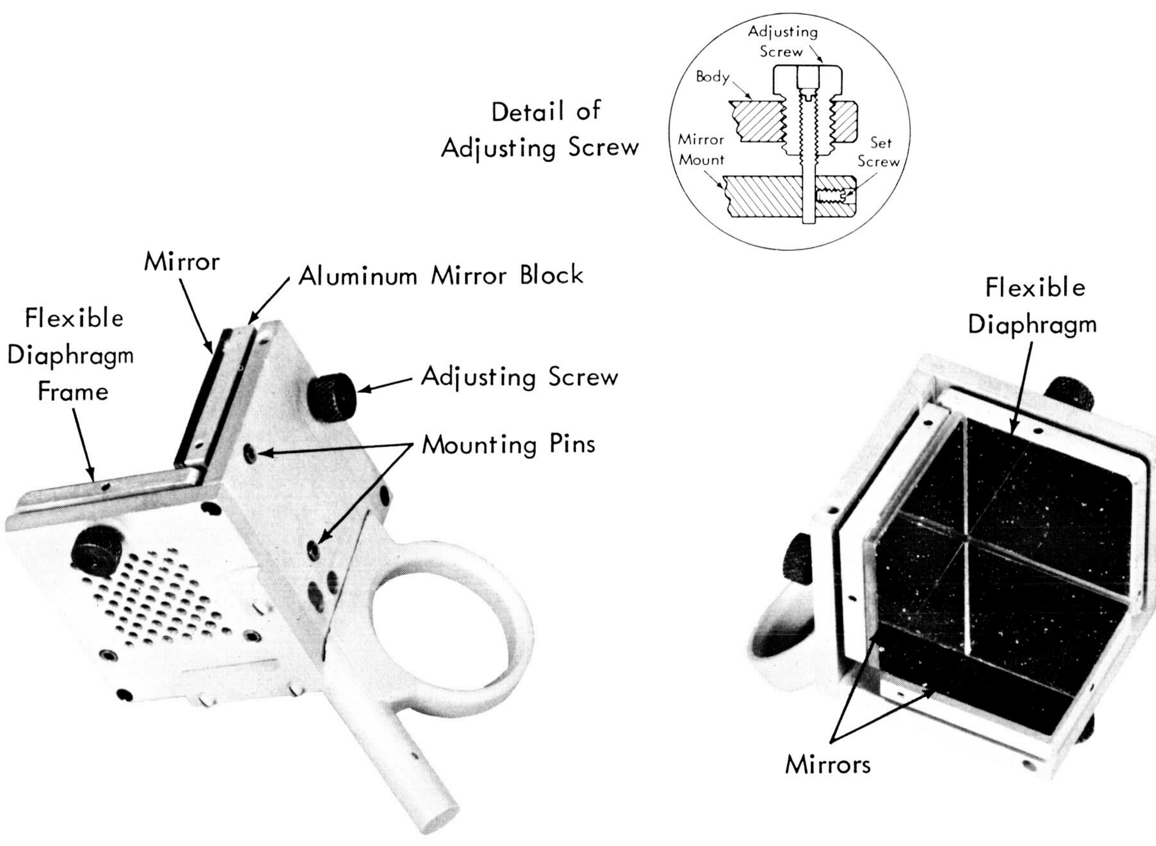


Figure 11. The corner reflector, shown actual size, has two front-surface 1 by 1 inch glass mirrors cemented to aluminium mounts, and one reflecting surface of aluminized Mylar cemented to an aluminum frame.

The corner reflector or passive modulator unit consists of a corner housing (Fig. 11) having three faces 1 inch by 1 inch in size. Two of the faces consist of front-surface mirrors cemented to aluminum backs. They are positioned on the housing by pins acting as pivots and by adjusting screws. The latter, in the model shown, are constructed with a small, finely threaded screw inside a larger screw with a slightly coarser thread. This permits screw travel equal to the difference in thread pitches, and thus allows microadjustment of the three mirrored surfaces. For simplicity, fine-thread machine screws (e.g., 1-72 or finer) fitted with lock nuts might perhaps serve for the delicate adjustments required.

The third mirror, the flexible diaphragm, is made of aluminized Mylar 1/2 mil thick. This is cemented to a beveled aluminum mounting frame that is also pivoted and screw-adjusted like the other two mirrors. Because fingerprints reduce Mylar's reflectivity, avoid touching the area that is to be cemented to the frame. For attachment, Eastman 910 contact adhesive or its equivalent will serve.

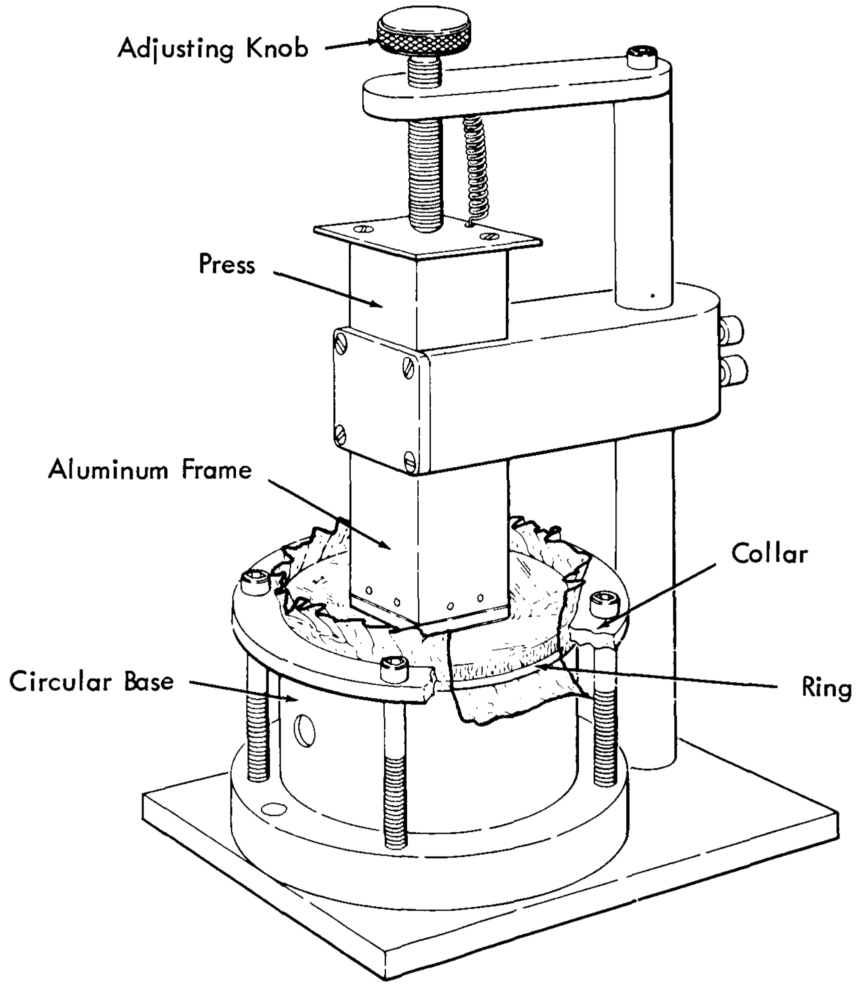


Figure 12. A fixture or press is useful when cementing the Mylar over its frame.

Because the Mylar must be tightly stretched over its frame to eliminate surface irregularities, a fixture is desirable to aid the stretching and cementing operations. The one shown in Fig. 12 was developed to cement a number of experimental diaphragms; a simpler fixture could no doubt be designed. With the press shown in Fig. 12, the following procedure works well:

a) Remove circular base, and place a sheet of Mylar, aluminized side down, over the base.

b) Place the ring over the Mylar, stretching the sheet evenly over the top of the base.

c) Then, bringing the excess Mylar up over the ring, add the collar and bolts to the assembly. Tighten the bolts evenly until the Mylar loses all dimples and wrinkles. Cut away excess sheet and place the circular subassembly on the bottom plate of the fixture.

d) Place a thoroughly cleaned aluminum frame, beveled side down, under the press and tighten the adjusting knob sufficiently to depress it firmly against the Mylar. Leave enough travel to afford space for a small bead of cement and yet enough pressure to prevent cement from running under the frame.

e) Using a medicine dropper with a tip that has been drawn down to a small diameter, add a bead of cement all around the frame. Then tighten until the Mylar is drawn up along the bevel of the frame.

f) Once the bond has been made, remove and trim the frame.

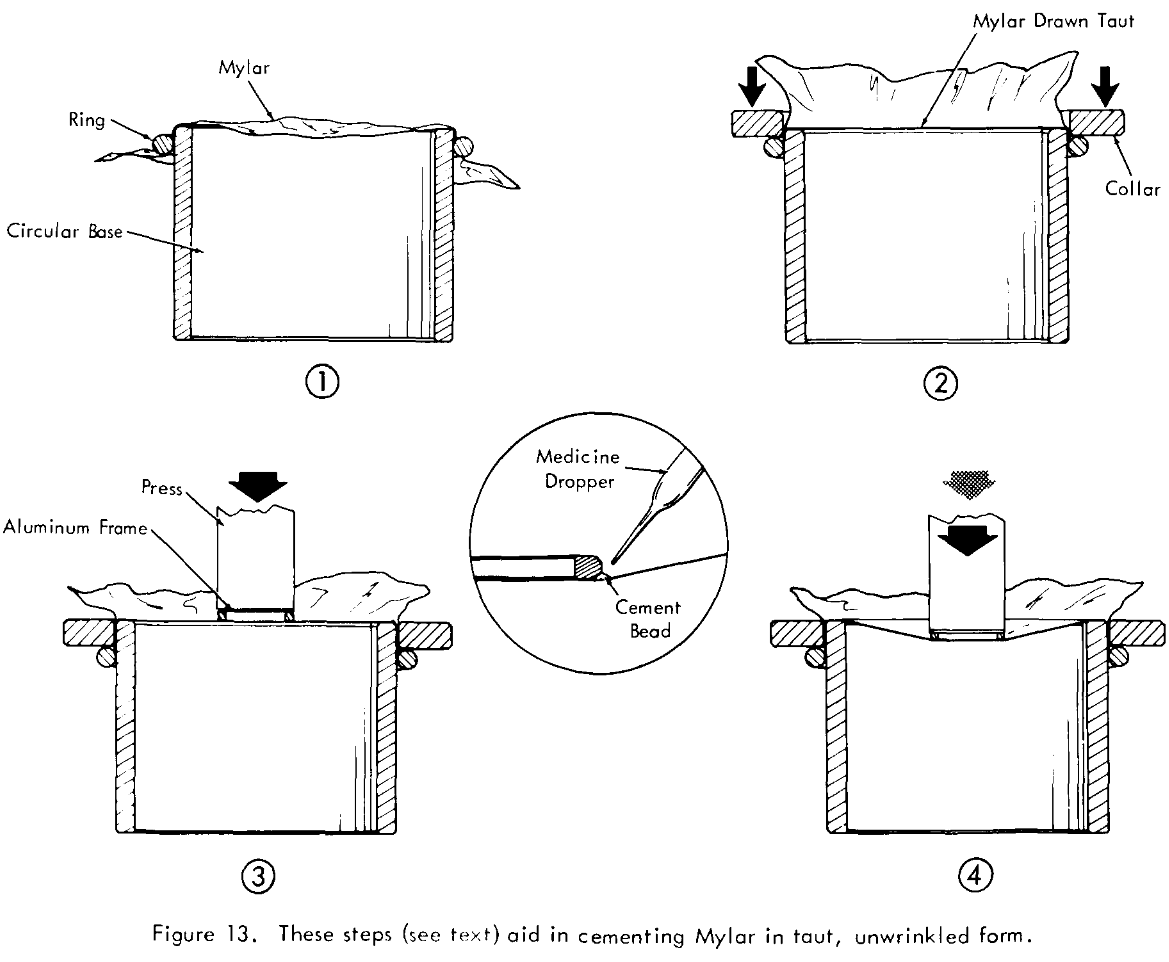


Figure 13. These steps (see text) aid in cementing Mylar in taut, unwrinkled form.

When the source/receiver and the corner-reflector unit have both been completed, it is necessary to adjust the reflector surfaces to precise perpendicularity. The following sequence will simplify the task:

a) Place the corner-reflector unit in a holding device.

b) Place the source/receiver in another holding device at a distance greater than 30 feet from the reflector, and aim the two units at each other.

c) Mount white cardboard behind the source/receiver unit, turn on the light source, and darken the room.

d) Then, without disturbing the aim of the corner reflector, adjust each reflecting surface to focus reflections on the card for minimum light spill around the shadow of the source/receiver.

Operate the source/receiver by turning on the power switch, adjusting the beam for a fairly broad spread, and pointing it at the corner reflector. When the reflector returns the beam and establishes communication, reduce the spread of the beam and adjust the volume control to a comfortable level.

Operate the corner reflector simply by aiming it at the source/receiver unit. When the light beam falls on the reflector, talk into the perforated housing at the rear of the flexible diaphragm. Determine experimentally the volume and closeness desirable at various ranges. Overmodulation---talking too loudly---can cause distortion or acoustic feedback at extremely close ranges.

8. Retrometer Patent Status

NASA encourages the immediate commercial use of this invention. It is owned by NASA, and a patent application has been filed. When patented, royalty-free nonexclusive licenses for its commercial use will be available. Inquiries concerning license rights should be made to National Aeronautics and Space Administration, Code AGP, Washington, D. C. 20546.

NASA-Langley, 1964